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Design and construction of a data recording
and processing system for geomagnetic field
coherence studies.

Huelsekopf, Gert-Wolfgang

Monterey, California. U.S. Naval Postgraduate School

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DESIGN AND CONSTRUCTION OF A DATA RECORDING
AND PROCESSING SYSTEM FOR GEOMAGNETIC FIELD
COHERENCE STUDIES

Gert-Wolfgang Huelsekopf

United States Naval Postgraduate School



THESIS

DESIGN AND CONSTRUCTION OF A DATA RECORDING
AND PROCESSING SYSTEM FOR GEOMAGNETIC FIELD
COHERENCE STUDIES

by

Gert-Wolfgang Huelsekopf

December 1969

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Design and Construction of a Data Recording
and Processing System for Geomagnetic Field
Coherence Studies

by

Gert-Wolfgang Hue lsekopf
Lieutenant Commander, Federal German Navy
B.S., Naval Academy Mürwik, Germany, 1962

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1969

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ABSTRACT

The design and construction of a data recording and processing system is described which permits simultaneous measurements from three proton free-precession magnetometers to be written onto tape at two second intervals. Detailed circuit diagrams and a computer program used for de-bugging the magnetic tape output are presented.

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I. INTRODUCTION

Since free nuclear precession in a weak magnetic field was first observed by M. Packard and R. Varian in 1953 [1] various magnetometers have been developed and constructed to measure magnitude, direction, or variation of the geomagnetic field.

A widely used magnetometer is the Proton Free-Precession Magnetometer. Its advantages are low cost, simplicity, ruggedness, and easy portability. In addition it needs no calibration and is virtually unaffected by changes in orientation and temperature. However, its sensitivity is much lower than that of the more sophisticated rubidium, helium and cesium devices.

The application of magnetometers in geomagnetic gradiometers is based on the assumption that the earth's magnetic field is invariant over short time periods (see i.e. Refs. 2-8). Witham and Niblett [9] have analyzed the errors introduced into aeromagnetic survey by geomagnetic time variations. They found that the rms differences in time variations are proportional to the rms level of magnetic activity and to the separation of two stations 50 feet and 26 and 94 miles apart. Duffus et. al. [10] have determined the short-range spatial coherence of geomagnetic micropulsations for stations 10, 50, 300, 950, and 1800 kilometers apart. The authors concluded that coherence was high only for moderate signal levels. Similar work was done by Jacobs and Sinno [11] and Wright [12]. So far, however, it is not known that detailed analysis has been carried out to show to what extent the assumption of short-time invariance of the geomagnetic field is valid for very short station separations. For this reason a solid state data recording and

processing system with three identical, individually controlled and monitored proton free-precession magnetometers was designed and constructed for the study of geomagnetic field coherence. The system allows simultaneous measurements at two second intervals from three magnetometers to be written onto magnetic tape for processing on digital computer and data analysis.

II. BRIEF INTRODUCTION TO THE PRINCIPLE OF OPERATION OF THE PROTON FREE-PRECESSION MAGNETOMETER

The Proton Free-Precision Magnetometer basically consists of a polarizing and sensing coil surrounding a proton sample such as kerosene. A dc polarizing current of two to three amperes applied to the coil with its axis oriented approximately normal to the geomagnetic field lines will produce a magnetic field in the sample which is about 200 times stronger than that of the earth. This field will cause the protons, which can be considered as tiny bar magnets, to align their longitudinal spin axes parallel to the magnetic field lines of the coil. When the polarizing current is turned off, the protons tend to realign themselves with their spin axes parallel to the remaining geomagnetic field lines.

During the process of realignment the protons precess coherently about the earth's magnetic field vector, \vec{H}_1 , at a frequency directly proportional to the magnitude, $|\vec{H}_1|$, of the geomagnetic field. This frequency of the proton precession can be used to determine the absolute geomagnetic field strength, if no other magnetic field than that of the earth acts on the protons, by:

$$\omega_L = 2\pi f_L = \gamma_p H_1 \quad (1)$$

where:

f_L = Larmor, or precession frequency of the proton,

γ_p = gyromagnetic ratio of the proton,

= proton magnetic moment/proton angular momentum.

The value of γ_p used in this paper is:

$$\gamma_p = (.267521 \pm .000002) \text{ gamma}^{-1} \text{sec}^{-1}$$

as found by Thomas [13] for mineral oil.

The precession signal as induced in the sensing coil is an exponentially decaying sinusoidal voltage in the microvolt range and is of the form:

$$v(t) = Ae^{-\alpha t} \sin(\omega_L t + \varphi(t))$$

where:

A = amplitude factor

α = attenuation constant

φ = phase shift.

For an earth's magnetic field strength of about 50,000 gammas (1 gamma = 10^{-5} Gauss), f_L is of the order of 2 kHz, since for protons in kerosene (mineral oil)

$$f_L = \frac{\gamma_p}{2\pi} \approx 4.3 \text{ kHz/Gauss.}$$

The technique used to measure the geomagnetic field strength is a cycle-counting method rather than a frequency determining method as will be shown below.

III. DATA RECORDING AND PROCESSING SYSTEM

A. GENERAL

Based on earlier work of Anderson [14] and Hansen [15] a data processing and recording system was designed and constructed which allows simultaneous readings from three proton free-precession magnetometers (Varian sensing head X 49 - 406A) to be processed and written onto magnetic tape for convenient data analysis.

Although the old system was still semi-operable, considerable time and effort were expended to significantly update the equipment, resulting in improved reliability and much higher resolution. All surplus transistors, which were demonstrating high failure rates, and all homemade circuit boards were replaced. This made it necessary not only to re-design most of the circuitry, but also to replace many system components.

A major interfacing problem developed when attempts were made to systematize old and new components. This resulted in a progressive replacement and renewal process. In the end, the only equipment retained from the old system were the magnetometer heads and the incremental tape recorder.

The exclusive use of Flip Chip Modules (Digital Equipment Corporation) in the logic circuitry provided the answer to the problem of reliable data processing and recording in a noisy environment.

Power requirements for the system outlined below are +10 volts at .5 ampere, -15 volts at 3 amperes, and -20 volts at 10 amperes. The size of the complete unit (except magnetometer heads, amplifiers, and incremental tape recorder) is 40 x 40 x 20 cm.

B. SYSTEM DESCRIPTION

Figure 1 shows a simplified block diagram of the data recording and processing system.

100 nsec pulses with a repetition rate of one every two seconds trigger three -20 volt/10 ampere drivers. The drivers simultaneously energize the polarizing coils of the magnetometers for a predetermined time (.4 to 1.3 second). Mercury wetted reed relays are used to prevent overloading the pre-amplifiers during the polarizing period.

After the polarizing field has collapsed and all transients from the magnetometer coil have died out the amplified proton precession signal with a usable duration of about one second is applied to the counting circuit the output of which is then written onto magnetic tape.

1. Timing Circuit

A block diagram of the timing circuit is shown in Figure 2.

Every two seconds the .5 Hz timer resets all counters and starts two monostable multivibrators (one-shots). One of the multivibrators produces a 800 msec pulse used to activate three relay drivers which open the reed relays. The 10-30 msec output pulse from the second multivibrator initiates another, 750 msec, one-shot which controls the polarizing current to the magnetometer coils. The relays are thus opened 10-30 msec before the polarizing period starts and connect the sensing coils to the pre-amplifiers only 20-40 msec after the polarizing current is turned off. An additional variable monostable multivibrator permits delay of the start of the counting cycle further if the transients from the collapsing field in the magnetometer coils extend beyond 20-40 msec.

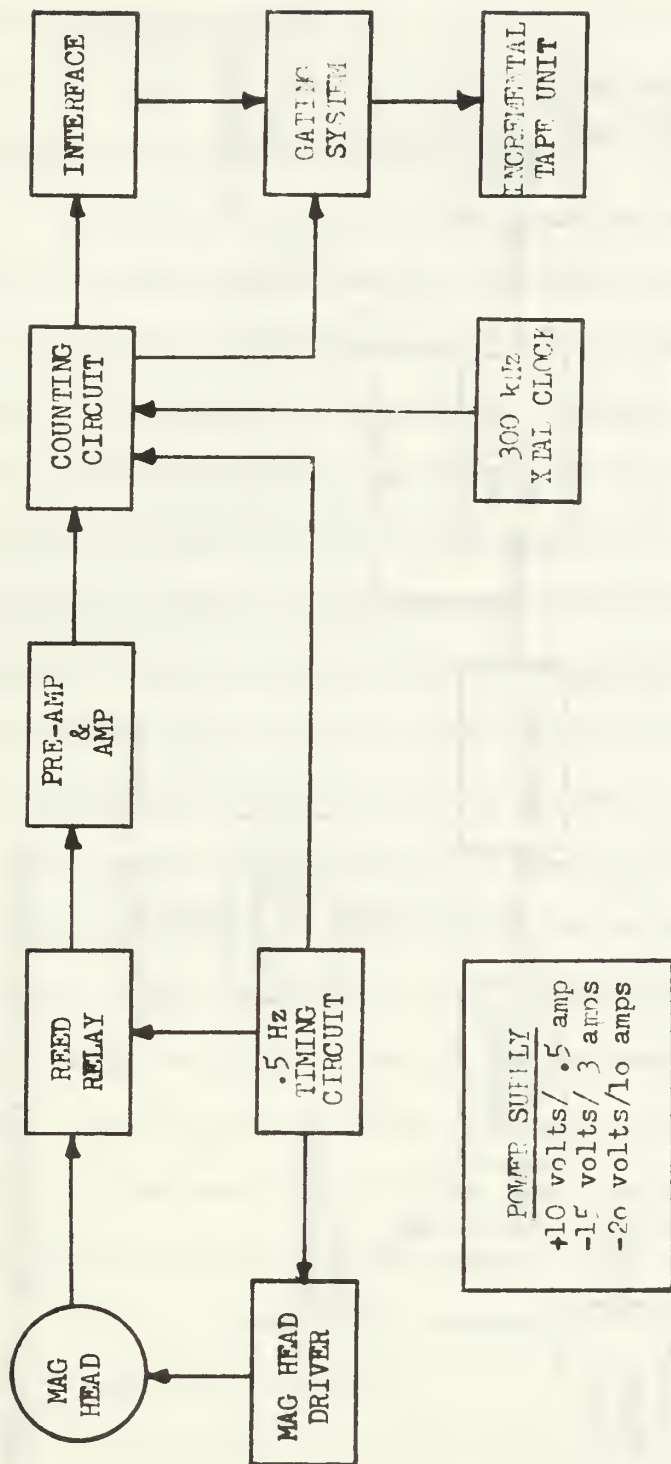


Figure 1: Data Recording and Processing System;
Simplified block diagram for one magnetometer

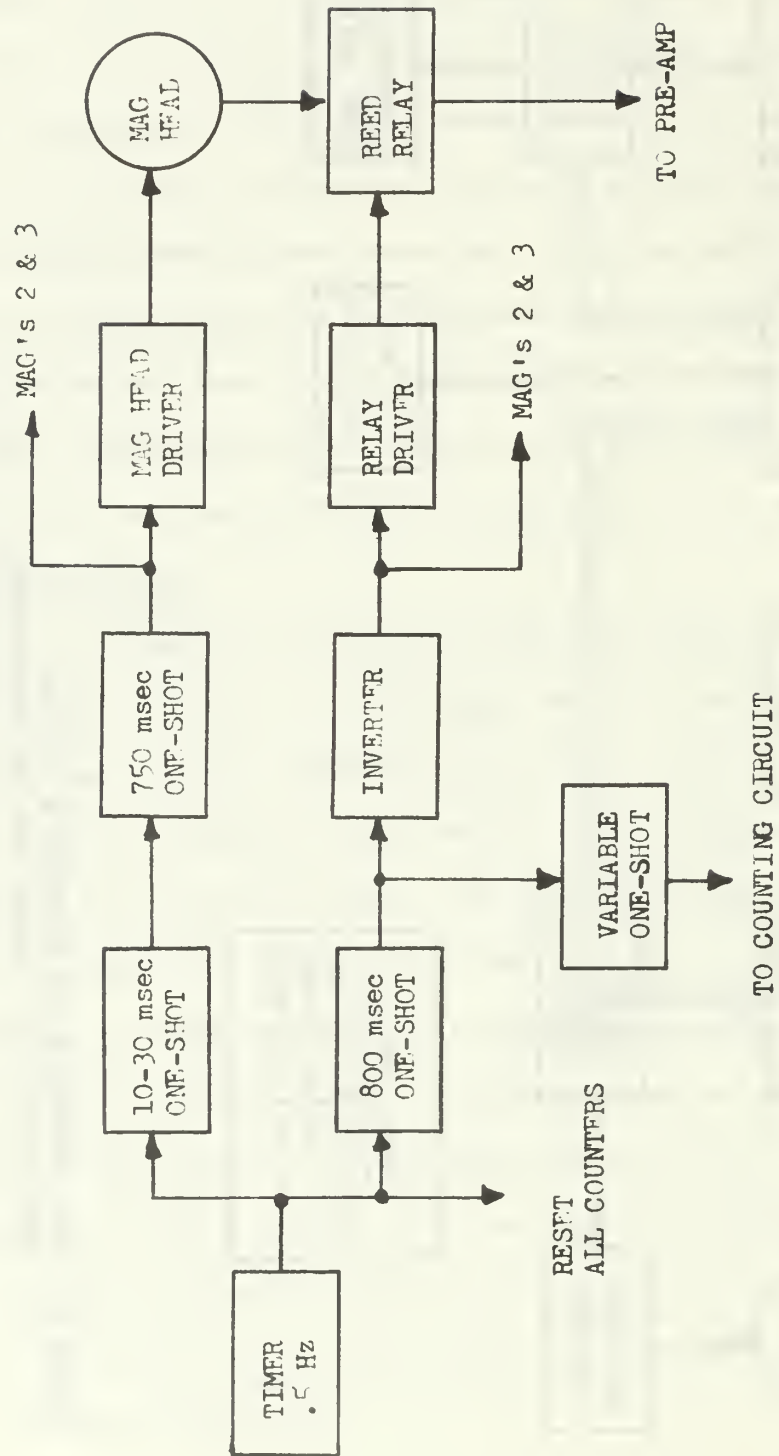


Figure 2: Timing Circuit, Block Diagram

Timing of all multivibrators is variable externally such that the precession signal amplitude and usable duration may be maximized according to experimental requirements.

2. Counting Circuit

As was pointed out above the geomagnetic field strength is determined by a cycle-counting method.

The usable duration of the proton precession signal of only about one second limits the time available to measure its frequency very accurately. For a geomagnetic field strength of about 50,000 gammas (the actual value in Monterey is about 50,950 gammas as found in Ref. 15) the signal frequency from (1) is approximately 2150 Hz. To detect a field variation of one gamma will thus require that the precession frequency be measured with an accuracy of $\pm .04$ Hz, a value which can hardly be achieved over a measurement time of around one second. This means that the error in field strength measurements due to the least cycle count would be ± 25 gammas, which cannot be tolerated. The most commonly used technique to improve the measurement accuracy is to count the number of high frequency pulses from a very stable crystal oscillator clock that occur during the time required to detect a fixed number of cycles (1024 in the system described) of the precession signal. For 1024 cycles of the precession signal with a period of $1/2150$, or .465 msec and a 300 kHz clock frequency, the accuracy of geomagnetic field strength measurements will be approximately one part in 1.4×10^5 , in other words, geomagnetic field variations of $\pm .35$ gamma or less can be detected.

A block diagram of the counting circuit is presented in Figure 3.

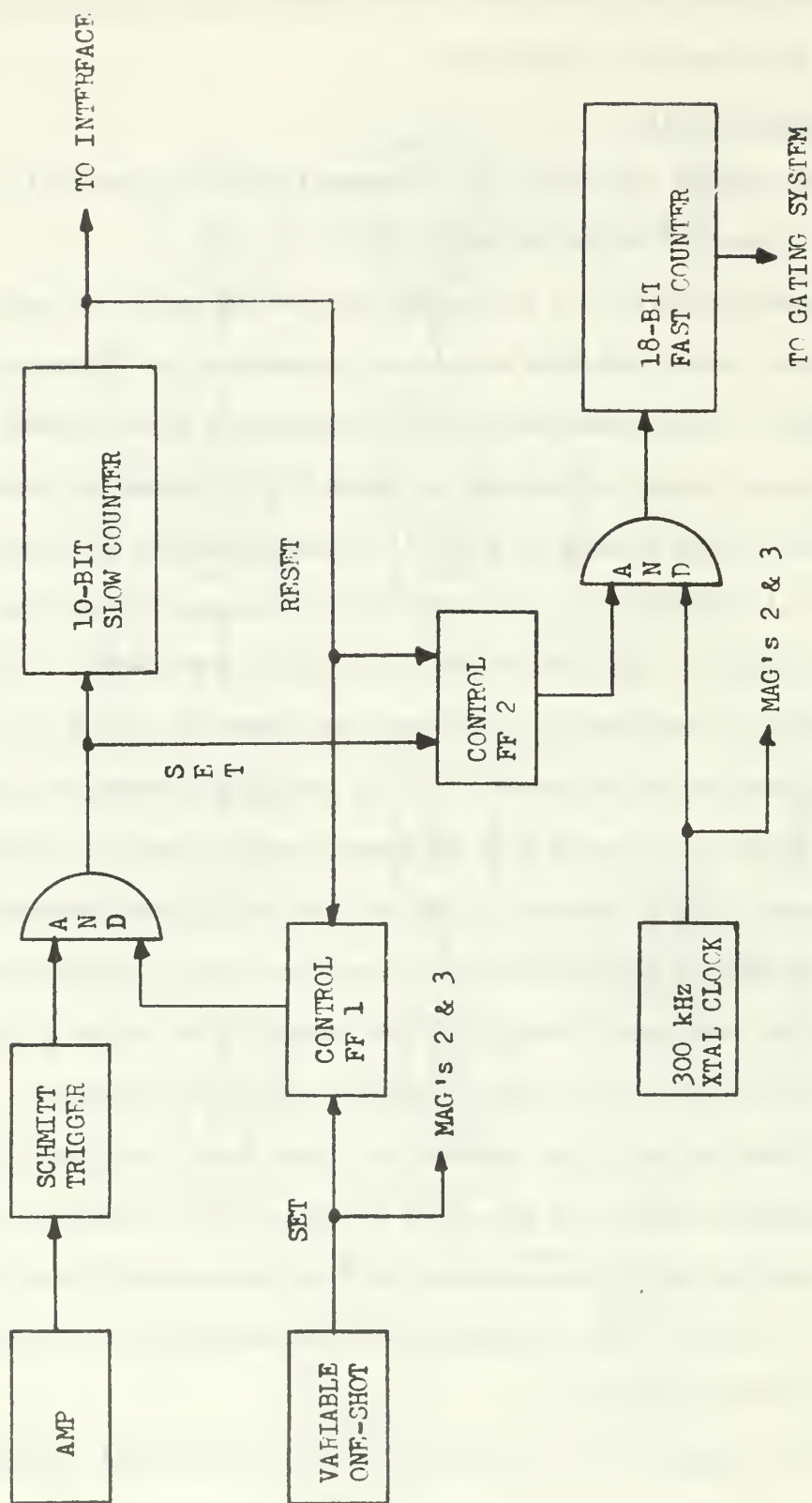


Figure 3: Counting Circuit, Block Diagram

20-40 msec after the polarizing current to the magnetometer coils has been turned off the amplified proton precession signal is applied to a Schmitt trigger which produces constant amplitude square pulses at the same frequency. Switching threshold levels of the Schmitt trigger were set to -2.2 volts and -0.8 volt to prevent, as much as possible, triggering by noise. Any input signal between ± 10 volts will not cause damage to the circuitry. The output of the Schmitt trigger is fed to an AND-gate which is enabled by control flip-flop 1 after all transients from the collapsing polarizing field have died out. The first pulse into the ten-bit slow counter sets control flip-flop 2 which in turn enables a second AND-gate. This AND-gate allows the 18-bit fast counter to count 100 nsec pulses from a 300 kHz crystal clock with an accuracy exceeding .01%. After 2^{10} cycles of the precession signal the slow counter resets control flip-flops 1 and 2, and the fast counter will hold the number of 300 kHz pulses counted for processing and writing onto tape.

If control flip-flop 2 is in its high state for 1024 cycles of the return signal from the magnetometer head the count of the fast counter, M, can be found from:

$$\frac{2^{10}}{f_L} = \frac{M}{f_c} \quad (2)$$

$$M = \frac{2^{10}}{f_L} f_c$$

where:

$$f_c = \text{clock frequency} = 300 \text{ kHz.}$$

Combining (1) and (2);

$$H(\gamma) = \frac{2\pi \cdot 2^{10} f_c}{M} \text{ gammas} \quad (3)$$

$$H(\gamma) \approx \frac{72 \times 10^8}{M} \text{ gammas}$$

Neglecting the propagation delay in the slow and fast counters which is .7 and 1.3 μ sec, respectively, and the gating speed of only a few hundred nsec it is apparent from (3) that the accuracy of geomagnetic field strength measurements depends largely upon M, hence the \pm last count error of the fast counter and the accuracy of the crystal clock. The ultimate limit on the accuracy, as derived in Ref. 15 is set by the signal-to-noise ratio of the precession signal which has to be at least 10 : 1 at the end of the last count in the slow counter.

3. Interface and Gating System

Figure 4 is a block diagram of the interface and gating system.

At the end of every counting cycle the slow counter of Magnetometer 1 starts a "step-write" cycle and

- sets the first bit of a ten-bit shift register to its high state and bits two through ten to their low states,
- fires two monostable multivibrators,
- starts a record gap timer.

The first nine bits of the shift register are used to sequentially enable six parallel AND-gates each so that the contents of the three fast counters are written onto tape in the order: bits 13-18 Magnetometer 1, bits 7-12 Magnetometer 1, bits 1-6 Magnetometer 1, bits 13-18 Magnetometer 2, etc. The tenth bit of the shift register terminates the "step-write" cycle.

The 10 msec one-shot steps the magnetic tape .005 inch on each trigger pulse received assuring that the tape is always in position when the next data character is up in the gating system.

The 3 msec one-shot, together with a second 10 msec one-shot, generates the shift pulses to the shift register. In this manner the

shift pulses are delayed with respect to the "step" pulses by 3 msec which allows data to be written onto tape only after the tape is positioned.

The record gap timer is a ten-bit up-counter which advances the tape .75 inch once every 2^{10} "step-write" cycles.

Included in Appendix A are detailed circuit diagrams for the complete logic system described above.

For further information on the logic modules used in the construction the interested reader is referred to the 1968 Logic Handbook issued by Digital Equipment Corporation, Maynard, Massachusetts.

C. DATA OUTPUT

An incremental tape recorder [15] was employed to write data on a standard seven-track, 1/2 inch magnetic tape with a density of 200 bits per inch. The tapes contained the measurement information in the following format: three six-bit characters for Magnetometer 1, three characters for Magnetometer 3, three characters for Magnetometer 3, followed by a 77_8 (all ones) character for identification, or, a total of ten characters per data set once every two seconds, with record gaps every 2^{10} data sets. A daily record of geomagnetic field strength measurements thus consists of 43,200 readings per magnetometer, or 432,000 characters.

It was found that due to noise on the 60 Hz power line the incremental tape unit was triggered from time to time accidentally causing more than one 77_8 characters to be written at the end of a data set. This, however, did not affect the quality of the records and could be taken care of by proper programming.

Because of the vast amount of data per daily record it was decided to use the SDS 9300 computer for intermediate processing and debugging only, and that future coherence analysis should be done on the IBM/360 computer.

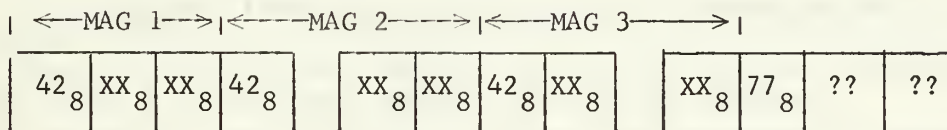
Processing and debugging of the data on the SDS 9300 used a priori knowledge about the magnetometer readings. The average earth magnetic field strength at Monterey is about 50,950 gammas [14] with daily variations claimed not to exceed ± 100 gammas. From (3) this field strength is related to the number of 300 kHz pulses counted in the fast counters during a measurement cycle, M, by:

$$M = \frac{2\pi \times 2^{10} f_c}{\gamma_p} \times \frac{1}{H(\gamma)},$$

so that M should be restricted to a range of approximately:

$$424000_8 \leq M \leq 425100_8.$$

Each data set will therefore start with an 42_8 character followed by another eight information characters and an indetermined number of 77_8 characters. An SDS 9300 word holds four bytes and data will be stored in buffer in the form:



indetermined number 77_8

Ideally (each data set being ten bytes only) each five computer words will consist of two readings from each magnetometer including the identifying character.

A computer subroutine "MAGDATA" (see Appendix B) was written using the following philosophy:

- search for the first 42_8 character
- take this and the next two characters and store them as $0042XXXX_8$, or the first data word
- make the next three characters data word 2 and store
- make the following three characters data word 3 and store
- dump all 77_8 characters following the third data word
- look for the next 42_8 character following the last 77_8 character dumped
- repeat the above up to record gap
- when end of record sensed write debugged data onto new tape
- continue until end of file.

Since the record gap timer is simply a ten-bit up-counter, each record contains 1024 readings/magnetometer, or a total of 3072 data words.

Writing record gaps every 10240 characters required 6000_8 storage locations each in the input and output buffers of the SDS 9300. An overall of 43 records/day were processed and debugged by this procedure and used not more than about one minute of computer time.

The only disadvantage of the above method is that in case the fast counter of Magnetometer 1 fails to function properly and the first character of a data set is not 42_8 , all data obtained is useless. It is therefore recommended that at least bits 13 through 18 of the fast counter of Magnetometer 1 be checked before and after each daily record and that a printout of the first and last records of each debugged tape be obtained before further processing.

IV. RESULTS AND CONCLUSIONS

The data recording and processing system described in this paper represents, by far, not the ultimate possible in compactness, overall accuracy, and cost. However, a considerable portion of the Flip-Chip Modules was already available and had to be used in order to avoid excessive expenditures. The construction faced severe time and supply problems, to date i.e., the crystal clock is not yet available so that final conclusions as to the absolute accuracy of the system cannot be drawn.

All components used proved to be very reliable, in more than 500 hours of operation no component failures have been observed. Continuous operation over a period of more than 120 hours with an ideal input signal substituting for the precession signal and a 300 kHz clock with an accuracy better than $\pm 10^{-3}\%$ showed identical readings from all three fast counters with a ± 1 count deviation as low as one per 100 measurements. The system was capable of following frequency changes of the ideal input signal down to $\pm .02$ Hz instantaneously, provided the input signal exceeded the threshold levels of -2.2 and -0.8 volts and supplied at least 2 milliamperes current per Schmitt trigger.

So far, actual geomagnetic field measurements could not be carried out because the pre-amplifiers and amplifiers built in 1964 [14] proved to be highly unreliable. The amplifiers showed the tendency to break into self-oscillations upon reception of any spurious signal from the magnetometer heads, such as transient noise, or relay noise. The actual precession signal could be observed by oscilloscope but was completely

masked by noise. Future incorporation of high performance operational amplifiers, such as the only recently marketed Fairchild μ A 741, should solve the problem of signal acquisition reliably. It is suggested that the pre-amplifiers be placed close to the magnetometer heads in a magnetically clean box and that passive filtering be used immediately following the pre-amplifiers to assure the required signal-to-noise ratio [15] at the input to the Schmitt triggers. A further improvement is possible by using separate charging and signal lines which was not attempted in the system outlined above. Since the transverse relaxation time of the protons is a direct function of the polarizing current, concern should also be given to the problem of increasing both the magnitude and the duration of the polarizing current which is possible within the limits of -12 to -25 volts and 400 to 1300 msec, respectively.

It is felt at this point that for preliminary geomagnetic field coherence studies the present system accuracy suffices. This accuracy will be limited by the $\pm .01\%$ accuracy of the crystal clock and corresponds to a measurement error of ± 5 gammas. For future experiments, particularly where the target detection problem is the major concern, the above error is intolerable and the implementation of a clock with an accuracy of at least one part in 10^5 becomes unavoidable.

To further increase the system sensitivity the clock frequency could be increased to 1 MHz which would necessitate extension of the fast counters beyond 18 bits and require that the clock accuracy be one part in 10^6 .

In conclusion the primary features of the system described here are:

1. all components are plug-in units for easy replacement
2. the system is rather compact

3. extension of the system in order to achieve greater accuracy and/or higher sensitivity is relatively easy
4. the timing circuitry is very flexible, with the exception that the data rate cannot be increased
5. reliability seems to be high
6. power requirements are moderate
7. data output is magnetic tape for easy computer processing and correlation analysis.

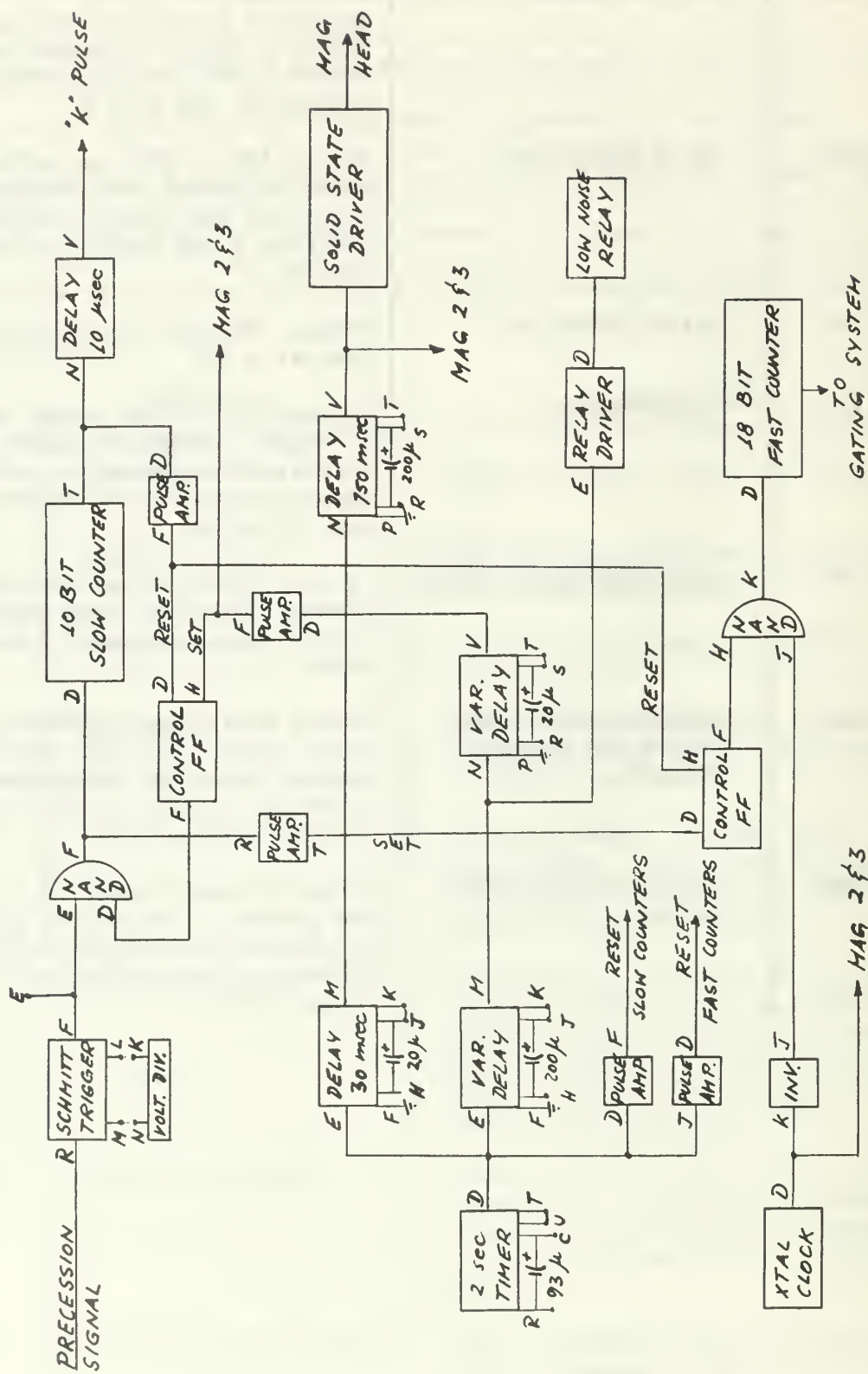
DETAILED CIRCUIT DIAGRAMS

Listed below are the D E C logic and other modules used in the construction of the system described above, together with their basic characteristics. Standard voltage levels are -3 volts and ground, logic levels are: logical 1 = -3 volts, logical 0 = 0 volt. All one-letter designators in the detailed circuit diagrams correspond to pin connections on the modules.

MODULE	FUNCTION	CHARACTERISTICS
R 107	INVERTER	Output standard levels -3 volts and ground
R 113	NAND/NOR GATE	NAND gate for negative inputs, NOR gate for ground levels
R 121	NAND/NOR GATE	2, 3, or 4 input gate, otherwise same as R 113
R 131	EXCLUSIVE OR	Output -3 volts for both inputs the same, output ground for different input levels
R 200	RS FLIP-FLOP	SET input makes 1 output go to -3 volts, RESET input makes 1 output go to ground. Inputs are 100 nsec pulses -3 volts to ground
R 202	DUAL FLIP-FLOP	Applications: up counter and shift register. SET, CLEAR, and SHIFT inputs 400 nsec standard pulses -3 volts to ground. 0 outputs used in 18-bit fast counters to match levels required for tape deck input
R 302	DELAY (ONE-SHOT)	Normal level is ground level. Output goes to -3 volts for predetermined time when input is triggered by positive going level -3 volts to ground
R 401	VARIABLE CLOCK (TIMER)	Output standard 100 nsec pulses -3 volts to ground at any frequency between 30 Hz to 2 MHz

MODULE	FUNCTION	CHARACTERISTICS
R 405	CRYSTAL CLOCK	Output 100 nsec pulses -3 volts to ground at specified frequency (5 kHz to 2 MHz). Frequency constant within $\pm .01\%$ for temperatures between 0° and $+55^{\circ}$ C
R 601	PULSE AMPLIFIER	Output 100 or 400 nsec pulses -3 volts to ground with standardized amplitude and width. Enabled by positive going levels, -3 volts to ground
R 603	PULSE AMPLIFIER	Output 100 nsec pulses, otherwise same as R 601
W 042	10 AMP DRIVER	10 amp of dc drive shared between 4 outputs. Negative input brings corresponding output to external supply voltage level between -12 and -25 volts
W 051	INDICATOR/RELAY DRIVER	-3 volt input brings output to ground. External load connected to any voltage between 0 and -12 volts
W 501	NEGATIVE INPUT CONVERTER AND SCHMITT TRIGGER	Ground level input produces -3 volts output, and vice versa. Nominal switching thresholds between 0 and -2.5 volts, minimum separation .5 volt
W 600	NEGATIVE OUTPUT CONVERTER	Converts input levels of -3 volts and ground to outputs of ground and an externally supplied voltage (between -1 and -15 volts), respectively

TIMING AND COUNTING CIRCUIT



[illegible]

NOTE:
ALL LETTERS CORRESPOND TO CONNECTIONS ON FLIP CHIP MODULES USED.

LOGIC:

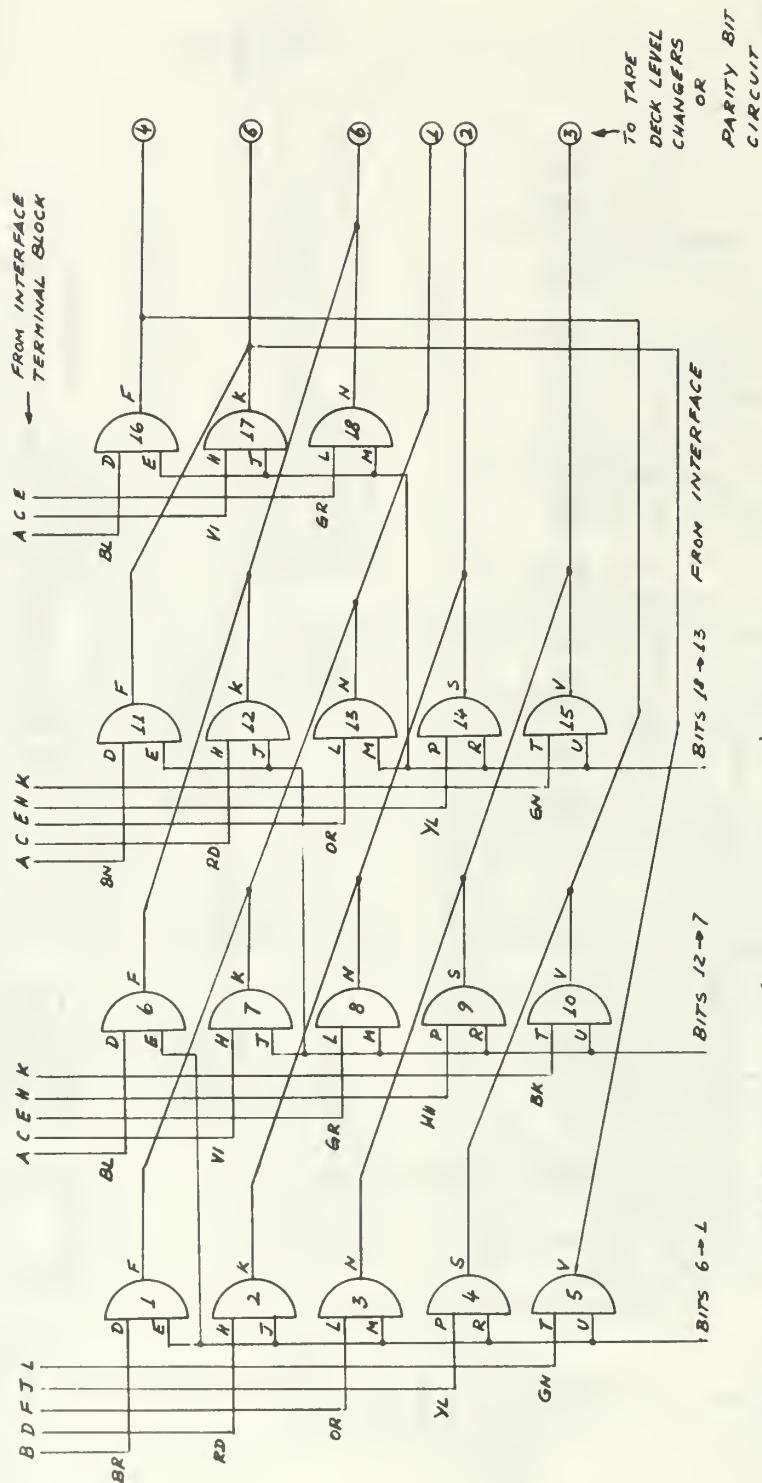
AIR COUNT: $\begin{cases} 0 \text{ VOLTS} = 1 \\ -4 \text{ VOLTS} = 0 \end{cases}$

SHIFT REG.: $\begin{cases} -3 \text{ VOLTS} = 1 \\ 0 \text{ VOLTS} = 0 \end{cases}$

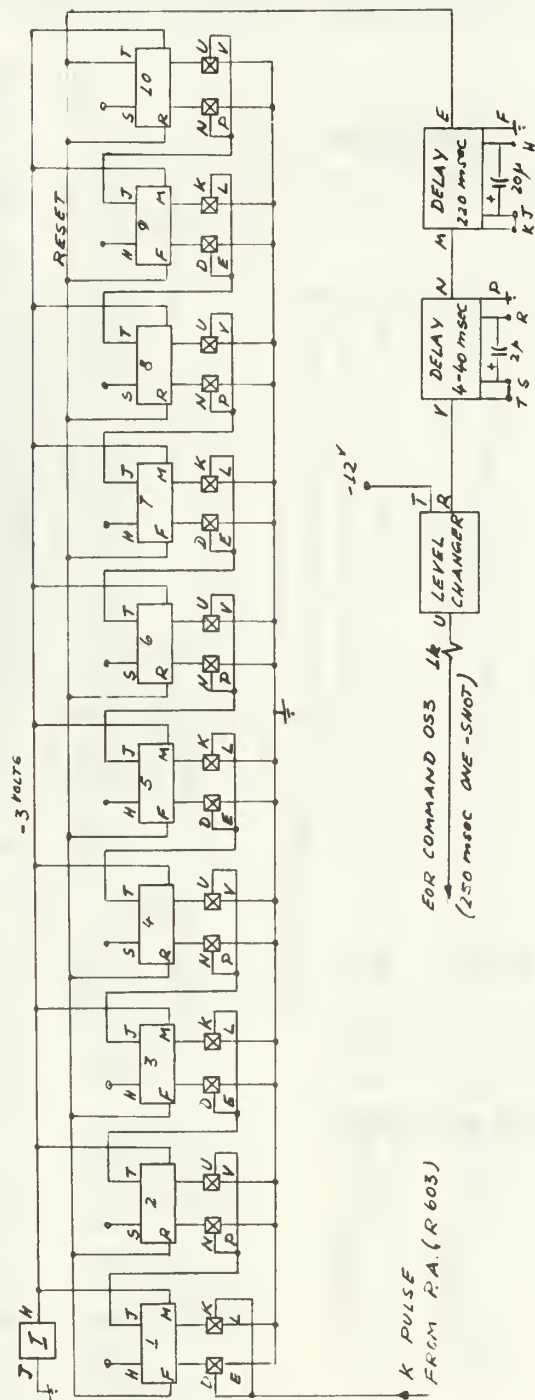
TAPE DECK: $\begin{cases} 0 \text{ VOLTS} = 1 \\ -12 \text{ VOLTS} = 0 \end{cases}$

R107 : INVERTER
R121 : NAND GATE
R131 : EXCL. OR GATE
R202 : J-K FLIP-FLOP
R302 : DELAY
R603 : PULSE AMP
W600 : LEVEL CHANGER

GATING SYSTEM FOR ONE MAGNETOMETER



RECORD GAP TIMER (10-BIT UP-COUNTER)



NOTES: ALL J-K FLIP-FLOPS R202 (2 EACH)

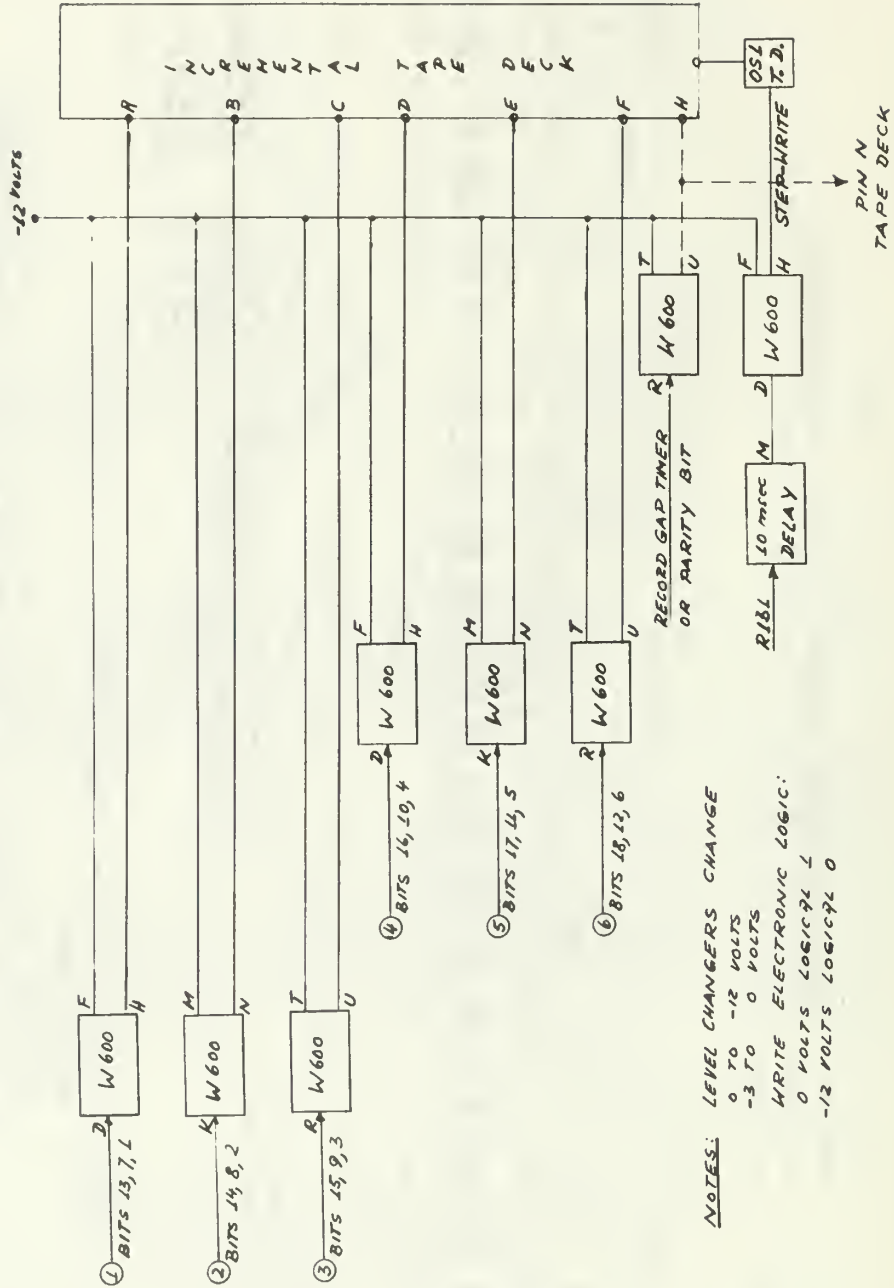
DELAYS R302

INVERTER R121

"RESET" NOT REQUIRED SINCE ALL ZERO STATE OCCURS AFTER 2¹⁰ COUNTS

1K RESISTOR IN SERIES WITH LEVEL CHANGER FOR ISOLATION

TAPE DECK LEVEL CHANGER



COMPUTER SUBROUTINE

* SDS 9300 SUBROUTINE "MAGDATA" FOR READING RAW DATA FROM RECORD TAPE 1,
* DEBUGGING THEM, AND REWRITING THEM SEQUENTIALLY IN BINARY ONTO TAPE 2

A	EQU	5	
B	EQU	4	
READ	TRT	0,1	READ TAPE 1
	CAT	0	
	BRU	\$-2	
	LDA	=040105777	
	STA	IN	
	XX	IN,1	
	COPY	(0,5)	
AGAIN	STA	IN,1	
	STA	OUT,1	
	BRX	AGAIN,1	
	LDB	=IN	
	LLSD	10	
	LRSB	10	
	LLSA	5	
	MRG	EOM	
	ADD	=3	
	STA	ALCIN	
	STB	INCW	
ALCIN	RTB	*0,1,4	
	EOM	014000	
	POT	INCW	
	CAT	0	
	BRU	\$-1	
	ASC	0	
	PIN	LASTW	
	LDA	=IN	
	STA	ADIN	ADIN IS INPUT BUFFER
	LDA	=OUT	
	STA	ADOUT	ADOUT IS OUTPUT BUFFER
	BRU	SEARCH	
INCW	PZE		
SEARCH	LDA	*ADIN	SEARCH FOR FIRST DATA WORD
	LDB	=077000000	
	SKM	=042000000	
	BRU	\$+2	
	BRU	SRCH1	
	LDB	=077700000	
	SKM	=077420000	
	BRU	\$+2	
	BRU	SRCH2	
	LRSB	6	
	SKM	=000774200	
	BRU	\$+2	
	BRU	SRCH3	
	LRSB	6	

	SKM	=000007742	
	BRU	\$+2	
	BRU	SRCH4	
	MPØ	ADIN	
	LDA	LASTW	
	ETR	=077777	
	SKU	ADIN	
	BRU	WRITE	
	SKG	ADIN	
	BRU	WRITE	
	BRU	SFARCH	
WRITE	TRT	0,2	WRITE TAPE 2
	CAT	0	
	BRU	\$-2	
	CØPY	(0,5)	
	LDB	=ØUT	
	LLSD	10	
	LRSB	10	
	LLSA	5	
	MFG	EØM	
	STA	ALCØUT	
	STB	ØUTCW	
	LDA	ADØUT	
	SUB	=ØUT	
	CØPY	(0,B)	
	LRSD	10	
	CØPY	(A,B),(B,A)	
	ADM	ØUTCW	
	CØPY	(B,A)	
	ADM	ALCØUT	
	LDX	=00177770,2	
WRIT1	WTB	*0,2,4	
ALCØUT	PZE		
	PØT	ØUTCW	
	CAT	0	
	BRU	\$-1	
	CET	0	ERROR TEST TAPE 2
	BRU	\$+1	
	BRU	READ	
	SRB	*0,2,4	
	EXU	ALCØUT	
	PØT	ØUTCW	
	CAT	0	
	BRU	\$-1	
	BRX	WRIT1,2	
	EFT	*0,2,4	
	EXU	ALCØUT	
	PØT	ØUTCW	
	CAT	0	
	BRU	\$-1	
	BRU	WRIT1-1	
EØM	EØM	014000	
ØUTCW	PZE		
SRCH1	CØPY	(0,4)	

	LRSD	6
	STA	*ADOUT
	MPØ	ADOUT
	MPØ	ADIN
	COPY	(0,5)
	LLSD	6
	LDB	*ADIN
	LLSD	12
	STA	*ADOUT
	MPØ	ADOUT
	COPY	(B,A)
	MPØ	ADIN
	LDB	*ADIN
	LRSB	12
	LLSD	6
	STA	*ADOUT
	MPØ	ADOUT
	LDA	LASTW
	ETR	=077777
	SKU	ADIN
	BRU	WRITE
	SKG	ADIN
	BRU	WRITE
	BRU	SEARCH
SRCH2	ETR	=0777777
	STA	*ADOUT
	MPØ	ADOUT
	MPØ	ADIN
	LDA	*ADIN
	MPØ	ADIN
	LDB	*ADIN
	LRSD	6
	STA	*ADOUT
	MPØ	ADOUT
	LRSB	6
	STB	*ADOUT
	MPØ	ADOUT
	LDA	LASTW
	ETR	=077777
	SKU	ADIN
	BRU	WRITE
	SKG	ADIN
	BRU	WRITE
	BRU	SEARCH
SRCH3	MPØ	ADIN
	LDB	*ADIN
	LLSD	12
	LRSD	6
	STA	*ADOUT
	MPØ	ADOUT
	LRSB	6
	STB	*ADOUT
	MPØ	ADOUT

	MPØ	ADIN
	LDA	*ADIN
	LRSA	6
	STA	*ADØUT
	MPØ	ADØUT
	MPØ	ADIN
	LDA	LASTW
	ETR	=077777
	SKU	ADIN
	BRU	WRITE
	SKG	ADIN
	BRU	WRITE
	BRU	SEARCH
SRCH4	MPØ	ADIN
	LDB	*ADIN
	LLSD	18
	LRSD	6
	STA	*ADØUT
	MPØ	ADØUT
	MPØ	ADIN
	CØPY	(B,A)
	LDB	*ADIN
	LRSA	12
	LLSD	6
	STA	*ADØUT
	MPØ	ADØUT
	LRSE	6
	STB	*ADØUT
	MPØ	ADØUT
	MPØ	ADIN
	LDA	LASTW
	ETR	=077777
	SKU	ADIN
	BRU	WRITE
	SKG	ADIN
	BRU	WRITE
	BRU	SEARCH
IN	RES	06000
ØUT	RES	06000
ADIN	PZE	
ADØUT	PZE	
LASTW	PZE	
	END	RFAD

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13. ABSTRACT The design and construction of a data recording and processing system is described which permits simultaneous measurements from three proton free-precession magnetometers to be written onto tape at two second intervals. Detailed circuit diagrams and a computer program used for de-bugging the magnetic tape output are presented.			

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KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

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WT

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geomagnetic field



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Design and construction of a data record



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